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THE USE OF PHYSICAL METHODS FOR PLANT GROWING STIMULATION IN BULGARIA

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ABSTRACT

Different chemical additives are used for rising productivity of plants and animals. Their application causes the contamination of raw materials for food production with toxins that is dangerous for consumers' health. On-farm safety for fresh produce needs developing and implementing new methods for quality assurance.

The influence of physical factors as microwave and laser radiation, magnetic field and ultrasound treatment is an alternative of soil additives and fertilizers. The substitution of chemical amelioration by physical one can reduce the toxins in raw materials and thus – raise the food safety. The use of some physical factors (laser irradiation; ultrasound influence; irradiation with microwave electromagnetic rays; magnetic field influence, gamma irradiation) for stimulation of seed vitality in Bulgarian agriculture has been discussed.

Key words: magnetic field, laser, microwave irradiation, ultrasound, gamma radiation, quantum agriculture.

INTRODUCTION

The growing need of ecological agricultural products together with the increased demand of vegetable raw materials for food production as well for other branches of industry imposes the necessity for searching new, safer decisions for raising the agricultural production.

Anthropogenic changes of the soil, waters, and atmosphere due to the use of different chemical additives for raising plants productivity led to searching alternative ways. Safe methods for increasing the yield include the reasonable use of chemicals and substitution of some of them by appropriate physical treatment.

The use of controlled influence of physical factors on biological behaviour during development of different cultures is a modern trend in combining the intensification of plant technologies with the ecological requirements.

Physical methods for increasing the vegetable production are based on the use of physical factors for plant treatment, particularly on the dill seeds with the major goal of increasing the yield and accelerating plant growth and development. Most perspective factors are the treatment with electromagnetic waves, particularly optical emission, magnetic field as well as the ultrasound and ionizing radiation. Recently the interest in the use of physical methods of plant growing stimulation has increased [9-11, 13-18, 23-28, 33-35, 69].

A range of surveys showed, that the development of the living organisms is strongly determined by the impact on different physical factors: magnetic field, parts of the electromagnetic spectrum, including gamma rays (Агафонова, [37]; Бекяров, [43]; Бляндур et al., [45]; Денчева et al., [52]; Инюшин et al., [55]; Vasilevski, [33]). Those factors highly define the natural environment for the plant growth and development and this may be the explanation for plant sensibility to their impact.

All living processes are highly dependent on energy exchange between the cell and the environment. In the case of chemical amelioration the necessary substances are directly inserted into the cell. In the case of physical treatment the energy introduced in the cell creates conditions for molecular transformations and as a result, the necessary substances are provided for the cell. This is the core concept in “quantum agriculture” that has been intensively discussed in the last years [36].

The present paper aims at surveying the use of physical factors for plant growing stimulation in Bulgarian agriculture. Application of the next physical factors was mostly used:

MAGNETIC FIELD

Numerous authors have found out that the influence of the stationary magnetic field on the seeds imposed their faster growth, activated protein formation and root growth [9-11, 13-17, 23, 26, 28]. Their investigations showed that magnetic field treatment of the seeds increased the germination of non-standard seeds and improved their quality. The reason for those reactions could be found in some paramagnetic properties of chloroplasts [13], situated in plant cells and representing the photosynthetic apparatus of higher plants.

Chloroplasts contain plant pigments (chlorophylls and carotinoides), their condition and structure being influenced by external factors. Data are available about the influence of ionizing radiations, light intensity and spectral distribution, temperature, water deficit, but there are no data about the influence of the magnetic field [80]. The investigation of the influence of the stationary magnetic field on plant photosynthetic apparatus is an attempt to bridge this gap.

An interesting review was published by Galland and Pazur [17] where plant sensibility to magnetic field treatment was thoroughly discussed. More than 250 papers published for over 60 years were cited in the review. Authors confirmed that a magnetic field of magnitude one or two orders above geomagnetic field strength (35 to 70 μT) could affect plant growth and metabolism. Some recent investigations on the influence of a stationary strong magnetic field have been added in the present paper. Samy [26] had found out earlier flowering and yield increase of cabbage as a result of the treatment with a magnetic field at 8-hours exposition. De Souza Torres et al., [14, 15] found out that treatment with a static magnetic field with induction of 0,08, 0,1 and 0,17 T increased the germination of tomato seeds by 5 to 25 %. Similar results for rice, sunflower and maize were reported by Carbonell et al. [10, 11] and M. Florez et al. [16].

It is necessary to point that Bulgarian investigations in the field of magnetic field treatment appeared in the last decade. The first experiments referred to the irrigation with water, treated in a magnetic field [54]. Later Фурджев et al. [82] mentioned about the treatment of rice seeds, but there was not a information about the magnetic field value. The effect of treatment was the yield increase by 4-5 %. Nedialkov et al. [21] found out that the pre-sowing treatment with a magnetic field showed a positive impact on seeds of soybean, maize, peas, okra, and beans leading to an increase of yield for soybean – by 48 %, for peas – by 15,7 %, for okra – by 19,6 %, and for beans – by 21,3 %, respectively.

Aladjadjiyan et al. investigated the influence of a stationary magnetic field with induction of 0,15 T at expositions 10 min, 20 min и 30 min, on maize seeds [2], soybean, cv.

Table 1 THE EFFECT OF MAGNETIC FIELD TREATMENT ON PLANT GROWTH

Plant	**Induction, *T***	**Exposition, *s***	**Response**	**Reference**
Wheat	0,03		3 % increasing length 5 % weight	Wyjcik [34]
Cabbage		8 hours	Increasing the length, yield	Samy [26]
Tomato	0,08- 0,1 0,17	600 180	5 to 25 % yield	De Souza Torres et al., [14, 15]
Rice	0,125 0,25	60, 600, 1200 1 hour	18 % germination	Carbonell et al. [10]
Maize	0,125 0,25	60, 600, 1200 1 hour	Increasing germination	Florez et al. [16]
Sunflower	0,125 0,25	60, 600, 1200 1 hour	Increasing germination	Carbonell et al. [11]
Asparagus			Increasing germination, length	Soltani et all. [28]
Rice	N/A	900, 1800, 3600	4-6 % yield	Фурджев [82]
Soybean Maize Peas Okra Beans		4, 8, 15, 30, 60	48 % yield - 15,7 % 19,6 % 21 %	Nedialkov et al. [21]
Maize	0,15	600, 1200, 1800	25 % germination 72 % weight 25 % length	Aladjadjiyan [2]
Tobacco	0,15	600, 900, 1200, 1800	68 % germination	Aladjadjiyan [6]
Soybean	0,15	600, 900, 1200, 1800	37 % germination 172 % weight 37 % length	Aladjadjiyan [5]
Caragana arborescens, Laburnum anagyiroides, Gleditsia triacanthos, Robinia pseudoacacia	0,15	600, 1200, 1800	Increasing germination 50 – 250 %	Аладжаджиян [39]

Daniela [5], tobacco seeds (Nicotiana tabacum L.), cv. Harmanly 11 [6]. Experiments with tobacco seeds were carried out with and without preliminary soaking for 24 hours in distilled water. In all the three variants it was found out that the treatment stimulated seed germination. The effect of the magnetic field treatment was stronger in preliminary soaked seeds.

Samples have been treated by a stationary magnetic field with induction B= 0,15 T. The magnetic field induction value was chosen according to the conclusions of Бонев, [47] that the weak magnetic field had a stronger effect on plant productivity.

Seeds of Caragana arborescens, Gleditsia triacanthos, Laburnum anagyroides and Robinia pseudoacacia were exposed to He-Ne laser, ultrasound, a permanent magnetic field and microwave radiation. Magnetic field treatment resulted in the highest values of 8 parameters measured, including the fresh weight and the length of the plant shoots. Germination was the fastest after magnetic field treatment, followed by laser and ultrasound treatments [39].

A comparison of the results obtained by some authors, not included in the review of Galland and Pazur [17], was presented in Table 1.

Presented data allowed concluding that:

The influence of the magnetic field treatment was investigated on the seeds of many different vegetable crops. The properly chosen treatment regime led to

Table 2 STIMULATION EFFECT OF LASER TREATMENT

Plant	Wavelength, *nm* /output power, *mW*	Duration, *s*/ Reiteration, *x*	Response	Reference
Sugar beat	632,8 / 20	/1,2,3,8,15x	Increasing 12 % germination	Стайков [76]
Soybean	632,8 /25	/1, 3, 5, 10x	Increasing 8-10 % germination	Димитров (1986) [52]
Wheat	632,8	/1, 3x	Increasing 20 % fresh weight 4 % length	Кименов et all. [57]
Maize	632,8/ 2,8$mWcm^{-2}$	360/	Increasing dry weight	Стоянова, Илиева [79]
Radish	632,8	120, 240/	Increasing 80 % weight	Ранков, Илиева [74]
Tomato	632,8/2,5 $mWcm^{-2}$	180, 360/	Increasing Germination weight	Илиева et all. [56]
Peas	632,8/ 2; 2,5	5, 15, 30, 60, 120, 240, 360/	Increasing weight	Найденова et all. [66]
Tulip	632,8/ 337/	15, 30 min 225, 450 pulses	Increasing Germination, length	Марков et all. [59, 60]
Maize	632,8 / 25	1x, 2x, 3x, 4x, 5x	Increasing yield 5,6 to 20,6 % (max at 2 *x*)	Влахова et all. [49]
Wheat	632,8		Increasing weight 3-14 %	Станкова et all. [78]
Pepper	632,8 / 2 $mWcm^{-2}$	5, 10, 15, 30, 60, 90,120/	3-14 % increasing germination and weight for dry seeds	Петкова, Генчев [68]
Alfalfa, clover, burr reed	632,8	3x	Increasing fresh weight, proteins 4,3-7,8 % length	Нанова, [67]
Cucumber	632,8/	180, 360/	Increasing growth	Ранков[73]
Tomato	632,8/ 2			Чолаков, [83]
Bean	632,8/ 40		Cytogenetic effect (chromosome aberrations)	Светлева, Аладжаджиян [75]
Linseed	632/20mW	3, 4, 5, and 6x	Increasing weight	Ivanova, [19]
Cucumber	632,8/ 20	/3+3+1*x* 2+2+2+1 *x* 1+1+1+1+1+1+1	Increasing yield 15,4 % 11,7 %	Чолаков, [86]
Cucumber	632,8/ 20		Increasing 42,4 % weight 13,5 % Chl content	Чолаков, [87]
Carrot	632,8/ 30	/5x, 7x, 9x	Increasing 5 % germination 7 % fresh weight	Аладжаджиян [40]
Cucumber	632,8/ 20	/ 7x	Higher quality seedlings	Cholakov, D. Petkova, V. [12]
Peas	632,8/ 17 457,9/ 90 488/ 260 514/ 285	Different doses	Cytogenetic effect (chromosome aberrations)	Василева M., [48]
Tomato Cucumber	632,8/ 20	Daily or night irradiation	7,6 % phytomass 5,7 %	Petkova, V. and Cholakov, D. [22]

improving plant growth parameters.

The positive effect of the magnetic field treatment was expressed in increasing the germination, bigger height and higher weight of the shoots compared to the control.

The influence of magnetic field treatment depended on the induction of the field, exposition of the samples and the pre-history of the samples.

The influence of preliminary soaking was only quantitative – the germination of the preliminary soaked seeds compared to the non-soaked increased by about 10 %. This observation could be due to the fact, that the water molecule also possessed paramagnetic properties and absorbed the energy of the magnetic field. This energy was also transformed into chemical one and it was an addition to the energy absorbed by the free radicals existing in the plant tissues of the non-soaked seeds.

Metabolically active tissues of the plant cells contain free radicals. They play an important role in electron transfer and in the kinetics of the chemical reactions. These free radicals possess non-paired electrons with magnetic moments that can be oriented in the external magnetic field. As a result of the interaction between the external magnetic field and the magnetic moment of unpaired electrons, the microwave energy was absorbed [13].

Table 3 THE EFFECT OF ULTRASOUND TREATMENT

Plant	Frequency, *kHz* /Power, *W*	Exposition, *min*	Response	Reference
Pepper Cucumber	20	1, 3, 5, 7 and 9	Increasing germination 15,6-20,6 % length maximum effect at 3&5 *min*	Марков [61]
Tomato	20	1, 3, 5, 7, 9, 11	Increasing germination 6-14 % yield	Марков [62]
Caragana arborescens, Laburnum anagyiroides, Gleditsia triacanthos, Robinia pseudoacacia	22 / 159	1, 5, 10	Increasing Germination, fresh weight and length of shoots	Аладжаджиян [38]
Carrot	22 /159	1, 5, 10	17 % germination 22 % fresh weight	Aladjadjiyan[4]

Table 4 THE EFFECT OF MICROWAVE TREATMENT

Plant	Wavelength, *cm* /Power, *W*	Exposition, *s*	Response	Reference
Soybean	2,45 GHz (λ=12)	6-12 min	Improvement of triglycerides distribution	Yoshida et all. [35]
Mustard, wheat, soybean, peas and rice	2,45 GHz (λ=12)		Elimination of microorganisms	Bhaskara Reddy et all. [8]
Winter wheat spring wheat, spring barley, oats	1 cm	20 min, 40 min	Increasing germination	Пономарев et all. [69]
bean	12 / 250	10, 20, 30	Increasing roots fresh weight 32-81 %	Aladjadjiyan [1]
Caragana arborescens, Laburnum anagyiroides, Gleditsia triacanthos, Robinia pseudoacacia	12 / 255, 425, 595, 850	30	Increasing germination, fresh weight and length of shoots (max at 425 *W*)	Aladjadjiyan [3]

This energy was later transformed in chemical one and accelerated the vital processes in seeds. The mechanism of energy absorption by molecules was different for the strong (1000A/m) and the weak (1 A/m) magnetic fields [47].

LASER EMISSION

After the creation of laser in 1960, a significant interest has been registered in the possibilities of its use for pre-sowing seed stimulation in plant-growing. Laser is a system emitting monochromatic coherent light wave.

A detailed review of the investigations in this field and an analysis of the possibilities of the method of laser treatment were presented by Инюшин et al. [55], as well as by Денчева et al. (51). Investigations on the effect of laser treatment on different plants were also performed by many Bulgarian scientists. Стайков [76], Влахова [49], Генчев and Петкова [50], Ранков and Илиева [74], Чолаков [84, 85], Svetleva and Aladjadjiyan [31], Светлева and Аладжаджиян [75], Чолаков [87] studied

Table 5 THE EFFECT OF GAMMA IRRADIATION

Plant	Source,	Doses, Gy	Response	Reference
Wheat	Cs-137	0-40	Increasing photosynthesis rate(max at 15-25 *Gy*)	Димов [53]
Sugar beet	Co-60	0,5 -100 *krad* 10-200 *krad*		Първанов [71, 72]
Maize		3, 5, 10, 15, 20, 30	Increasing yield 6 – 118 % (10*Gy*)	Антонов [42]
Maize		0,25, 0,5, 0,75, 1, 1,25 *krad*	Increasing yield 5 to 9 % (0,75 *krad*)	Влахова et all. [49]
Potato		3, 5, 7, 10	Increasing yield 7 -23 %	Стайков et all. [77]
Sunflower		1, 2, 3, 4 *krad*	Increasing yield 5 to 19 %	Тюфекчиева [81]
Tomato	Co-60	10	Increasing photosynthesis	Petkova, Cholakow, [22]
Peas	Co-60	80, 100	Decreasing growth rate with 36 and 46 %	Stoeva [29]
Bean	Co-60			Stoeva, Bineva [30]

1 *rad* = 10^{-2} *Gy*

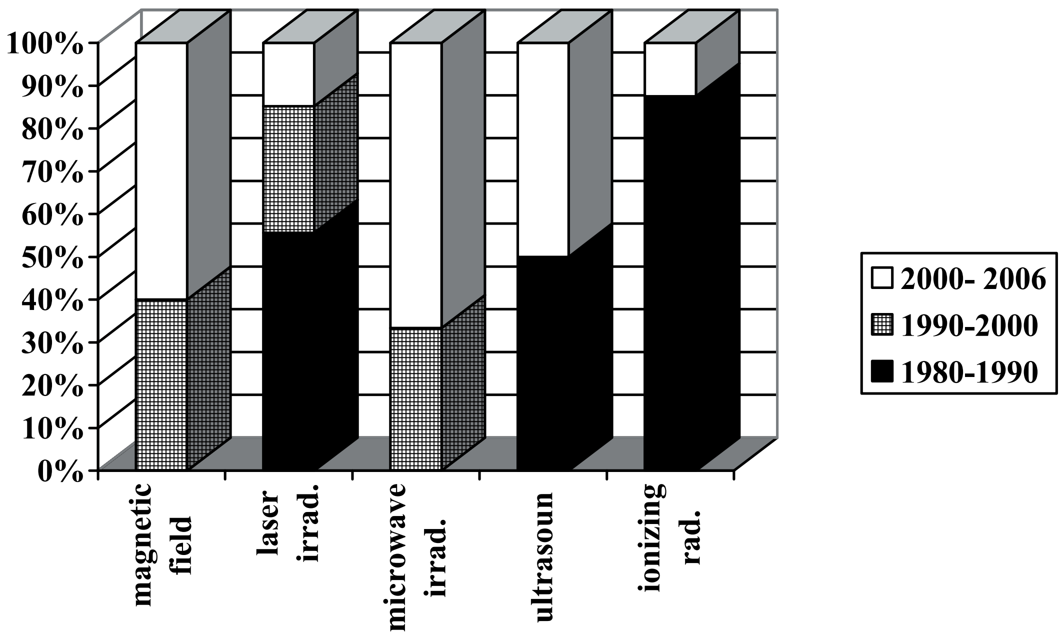

Fig.1 - The distribution of the investigations of physical methods for plant stimulation in Bulgarian agriculture by years during the last three decades

the impact of laser treatment on a number of vegetables and cereals – peas, tomatoes, cucumbers, peppers, radishes, wheat, corn, soybean and sunflower.

Марков [59], Марков et al. [60] investigated the impact of radiation of helium - neon laser on tulips and gladioli. In the second study a comparison between the impact of helium – neon and nitrogen laser, emitting at a wave-length of 337 nm was made.

Ранков [73] analyzed the influence of helium - neon laser irradiation at exposition of 180 and 360 s on the vegetative behaviour of cucumber seedlings. Петкова and Генчев [68] explored the influence of of helium - neon laser irradiation at expositions from 5 to 90 s on the dynamics of the germination and dry matter accumulation in peppers. Станкова et al. [78] studied the influence of the duration of the seed stay-aside between the moment of the irradiation and the moment of sowing on the productiveness of soft winter wheat.

Due to the impact of helium-neon laser, an acceleration of germination and development at the early phases for dill seeds of different cultures was established: peas [48], alfalfa, clover, burr reed [67], tomatoes [83], cucumbers [86, 87]. The positive effect of the treatment was expressed in increasing of the germination, bigger plant height, higher weight of 1000 seeds in comparison with the control. In the paper of Василева [48] the influence of argon laser on peas was investigated, too. It was found out that the strongest phytogenetic effect was reported after the irradiation with wavelength of 588 nm. Preliminary soaking of seeds led to a stronger effect. The cytogenetic effect of the He-Ne laser treatment of common bean was also studied in [75]. The authors also confirmed that the preliminary soaking of the seeds enhanced the effect of the treatment. The influence of the rhythm and the period of irradiation with He-Ne laser on the biological characteristics of tomatoes [84, 85] and cucumbers [86] was also studied.

The results about the Bulgarian investigations on the effect of pre-sowing laser irradiation of seeds on their development were presented in Table 2. Most studies were carried out using He-Ne laser with wavelength of 632,8 nm. In one of the investigations a comparison of the influence of four different wavelengths [48] was made. Some authors found out that preliminary soaking of the seeds in distilled water guarantied higher stimulation of the development for bean [31]. The influence of seed humidity on the effect of treatment was studied for cucumbers [87]. Other authors mentioned about the importance of mineral feeding combined with laser irradiation [73, 74] and the number of reiteration [12, 86]. Because of the simultaneous variation of more than one parameter of the experiments (i.e. exposition and reiteration or mineral feeding) some of scientists were not convinced in the effectiveness of laser treatment.

Having in mind all presented papers we can conclude that the influence of laser irradiation on plant behaviour was the most thoroughly investigated physical factor in Bulgarian agriculture. It was used for stimulation in a big number of vegetables and other plant species. It was found out that the effect of stimulation depended on the laser wave length, the exposition on irradiation, the reiteration and the pre-history of the samples (i.e. preliminary soaking of seeds in water).

In the case of laser treatment the stimulation was due once again to the increasing energy supply of seeds. In that case the photon energy of laser radiation was absorbed by chlorophyll and directly affected the photosynthetic intensity. The effect of enhancement of preliminary seed soaking could be attributed to water inhibition by cells. That should have made the cell membrane thinner and hence its transparency for laser radiation could increase.

ULTRASOUND

Ultrasound is a mechanical wave having frequency higher than 20 kHz. The effect of ultrasound plant stimulation can be explained again by rising molecular energy because of electron-phonon interactions.

It was established that the treatment with ultrasound irradiation could change the state of the substances and even accelerate the reactions. This fact motivated its application for stimulating the growth of different cultures [25, 33, 37-40, 43, 44, 46 and 70].

Божанова [45], Попов [69] applied ultrasound treatment to different seeds and as a result of the proper regime they established increased plant development and yield. Most of the authors recommended the treatment with ultrasound of frequencies 15 – 100 kHz and exposition from 1 to 15 min, with radiation density between 1 and 10 Wcm^{-2}.

The effect of ultrasound treatment with a frequency of 22 kHz and a power of 150 W on the germinating energy and germination of carrot seeds (Daucus carota L.), cv. Nantes was studied [40]. The maximum effect was found out for 5 min treatment.

Seeds of Caragana arborescens, Gleditsia triacanthos, Laburnum anagyroides and Robinia pseudoacacia treated with ultrasound showed increased seed germination, fresh weight and length of shoots [38].

It could be concluded that the use of ultrasound treatment also played the role of a plant stimulation factor.

MICROWAVE RADIATION

Electromagnetic radiation from the microwave diapason is absorbed by electrons in molecules. The treatment with microwave radiation can cause transitions of electrons between rotation sublevels. Transitions between vibration levels of organic molecules are in near infrared regions, and those between rotation levels are in far IR regions and near microwave regions of the electromagnetic spectrum.

It was accepted [18] that the effects of microwave irradiation were attributed to microwave heating. Recently, Banik et al. [7], reviewed the bioeffects of microwave. They mentioned that there were non-thermal microwave effects in terms of energy required to produce molecular transformations.

Bhaskara Reddy et al. [8] used successfully the irradiation with electromagnetic radiation from the radio- (10-40 MHz) and micro-wave diapason (2,45 GHz) on seeds of mustard, wheat, soybean, peas and rice aiming at the elimination of microorganisms before seed storage.

Yoshida et al. [35] treated soybean seeds with microwave radiation (2,45 GHz) for 6 to 12 min aiming at improving the distribution of triglycerides in the seed coat. In both above-mentioned studies the microwave treatment was targeted at the producing effects not related to plant stimulation.

Пономарев et al. [69] investigated the influence of microwave radiation on the germination of cereals (winter and spring wheat, spring barley, oats). Radiation with wavelength λ = 1 cm at exposition to 40 min was used. An increasing of germination for all the treated seeds was observed, the optimum effect of stimulation being accounted at the exposition for 20 min.

This kind of treatment is not very well known in agriculture as a stimulating agent. We tried to investigate the stimulation effect of microwave treatment on bean (Phaseolus Vulgaris) [1] and on some ornamental perennial species Caragana arborescens Lam., Robinia pseudoacacia L. Gleditsia triacanthos and Laburnum anagyroides Med.[3]

In the case of bean seeds the treatment was performed with wavelength of λ=12 cm and output power of 250 W for 10, 20 and 30 s. The longer the treatment, the higher stimulation was achieved expressed in a bigger fresh weight of roots and germs. Preliminary soaking of seeds in distilled water increased the effect of stimulation by more than 25 % [1]. That fact might be due to the specific absorption of microwave radiation with wavelength of λ=12 cm by the water molecules. The higher energy supply led to more intensive molecular transformations.

In the case of perennials a microwave treatment with wavelength of λ=12 cm with output powers: 255, 425, 595, 850 W, and exposition 30 s was studied. An increase of germination was observed, with a maximum for the treatment with 425 W [3].

The use of microwave irradiation in Bulgarian agriculture was reviewed in Table 4 along with some recently published works about non-thermal use of microwave irradiation in plant sciences.

On the basis of the results obtained it is possible to suggest a promising future for the microwave radiation as a plant stimulation factor.

GAMMA RAYS

The effect of ionizing radiation on plant growth has been studied since 1897, beginning with the influence of X-rays [27]. Later the effect of gamma-irradiation was also investigated thoroughly [29, 32].

Although the biological effects of large doses of ionizing radiation are predominantly harmful, low to intermediate doses have been observed to enhance growth and survival, augment the immune response and increase the resistance to the mutagenic and clastogenic effects of further irradiation in plants, bacteria, insects and mammals. The existence of these stimulatory, or “adaptive” responses implies that the dose-response relationships for genetic and carcinogenic effects of radiation may be similarly biphasic, or hormetic in nature, a possibility with far-reaching implications for radiation protection [32].

In Bulgarian agriculture the treatment with ionizing radiation has also been largely investigated. The paper of Димов [53] on the application of ionizing radiations on some Bulgarian wheat varieties was published recently. He established an increase of the photosynthetic rate and chlorophyll a and b content in the treated samples, but a decrease of the carotinoids content in comparison with non-treated ones.

A comparison between the effectiveness of gamma rays and laser treatment has often been made. Weaker doses and twofold irradiation were found most effective in the case of maize and sunflower seeds stimulation, but not as effective as laser irradiation [49], [81]. Petkova and Cholakov [22] found out that the combination of gamma and laser treatment was more effective compared to the separate application of each of both agents. The effect of gamma irradiation was compared with that of irradiation with fast neutrons [71, 72]. Combined gamma-irradiation and chemical mutagens were used to induce mutations targeted to genetic improvement of crops [20].

During the 80-ies the influence of gamma-irradiation on different properties of some aromatic and pharmaceutical plants was investigated [58, 63-65]. The possibilities of improving parameters of Verbascum pseudonobile L. (alkaloids content) [64], Calendula officinalis L. (carotinoides content) [58], Hissopus officinalis L. (flavonoids, saponins, etheric oil) [63], Salvia Sclarea (flavonoids content) [65] and earlier germination were established after irradiation with Co^{60} gamma-rays with doses between 10 and 100 krad. At higher irradiation doses (over 50 kr) the viability coefficient of plants was too low - up to 15 %.

An overview of the recent use of gamma irradiation in Bulgarian agriculture was presented in Table 5.

Concerning the reviewed papers we can conclude that gamma-irradiation plays a significant role in plant-growth stimulation.

CONCLUSION

Living systems have mastered the making and breaking of chemical bonds, which are quantum mechanical phenomena. Absorbance of frequency specific radiation (e.g. photosynthesis and vision), conversion of chemical energy into mechanical motion (e.g. ATP cleavage) and single electron transfers through biological polymers (e.g. DNA or proteins) are all quantum mechanical effects.

Experimental investigations of the physical factors influence on plant development may help to elucidate the mechanisms of energy exchange in molecules and thus stimulation of plant development.

The distribution of the investigations of physical methods for plant stimulation in Bulgarian agriculture during the last three decades by years and by treatments used was presented in Figure 1. It allowed concluding that magnetic field treatment and microwave irradiation were more perspective than the other reviewed methods.

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